

ACTION OF ACOUSTIC EFFECTS AT ION IMPLANTATION ON KINETIC PROCESSES IN CARBON FILMS

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Abstract

Variable stresses originating due to energy, impulse and volume transfer at low-energy C^+ , Ar^+ ions implantation in carbon films are theoretically investigated. A spatial dependence of generated pulse is analyzed taking into account the sound absorption. The influence of the elastic waves on kinetic processes in irradiated matter is discussed.

INTRODUCTION

Experiments show a remote action of low-energy ions on properties of deposited film on depths considerably exceeding the ion ranges. The thermodynamic conditions in thermoelastic peaks (TEPs) – nanometer regions around ion trajectories containing thermalized ion energy were investigated in [1]. It was shown that a powerful acoustic pulse is generated in TEP due to energy E and volume V_1 introduced by ion. The stress pulse is a spherical bipolar wave diverging with the longitudinal sound velocity s . Its amplitude in the wave zone can be represented as

$$\sigma(r_0, t) = \frac{1}{2} \frac{st}{r_0} \cdot \frac{\Gamma E \eta + K V_1}{V} \left[H\left(t - \frac{r_0 - R}{s}\right) - H\left(t - \frac{r_0 + R}{s}\right) \right], \quad (r_0 \gg R) \quad (1)$$

where t is time counting from the moment of TEP origination, \vec{r} – radius-vector from TEP center to the observation point, $H(t)$ – the Heaviside's unit, $\eta = \eta(E)$ – a part of ion energy transferred to the phonon excitations, $R = R(E)$ and $V = V(E)$ – radius and volume of TEP, K – the compression modulus and Γ – the Gruneisen parameter of a target material. Taking from [1] data concerning $\eta(E)$, $R(E)$ and $V(E)$ we get estimate $\sigma(R) \sim 10$ GPa. Such stresses can stimulate rearrangement of carbon to sp^3 bonds, result in change of rate of kinetic processes in irradiated material (i.e., creep, diffusion of impurities and interstitials, etc.) To right estimate the acoustic effect action on radiation – stimulated processes one need to take into account all basic mechanisms of elastic wave generation. Particularly, the generation of high pressure pulses also takes place due to transfer of the ion momentum $P = \sqrt{2ME}$ to the target material during the time of ion-ion relaxation τ . Such impact pressure $p_D \sim \sqrt{2ME}/(\pi R^2 \tau)$ in front of TEP exceeds the material yield stress and is able to cause structural rearrangements (the radiation cold hardening), to move the surface atoms in depth of the material, etc. In this paper by the example of C^+ и Ar^+ ions with energy from 25 to 1000 eV bombarding carbon target the contributions of different mechanisms of elastic wave generation are determined and compared. A spatial dependence of the pulse amplitude including a sound absorption is investigated. The action of variable stresses from ion TEPs on kinetic processes in irradiated material is discussed.

RESULTS AND CONCLUSIONS

The acoustic stress generated due to transfer of impulse \vec{P} from incident ion to TEP material was estimated in the hydrodynamic approximation:

$$\sigma_D(\vec{r}_0, t) = -2s \frac{\sqrt{ME}}{V} \frac{R}{r_0} \cos \theta e^{-(st - r_0 + R)/R} \sin\left(\frac{st - r_0 + R}{R} - \frac{\pi}{4}\right) \quad (2)$$

Here θ is the angle between the direction on the observation point and vector \vec{P} . Note that the impact stress depends on θ in accordance with the law of dipole radiation: $\sigma_D \sim \cos \theta$.

The energetic dependence of ratio σ_D/σ for C^+ и Ar^+ ions at $\theta = 0$ is shown in Figure 1. One can see that the impact stress is comparable or exceeds the thermoelastic and deformation ones.

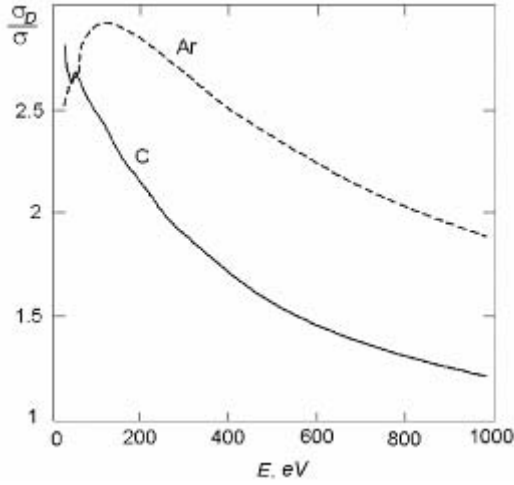


Figure 1. Energetic dependence of ratio σ_D/σ for C^+ and Ar^+ ions in carbon

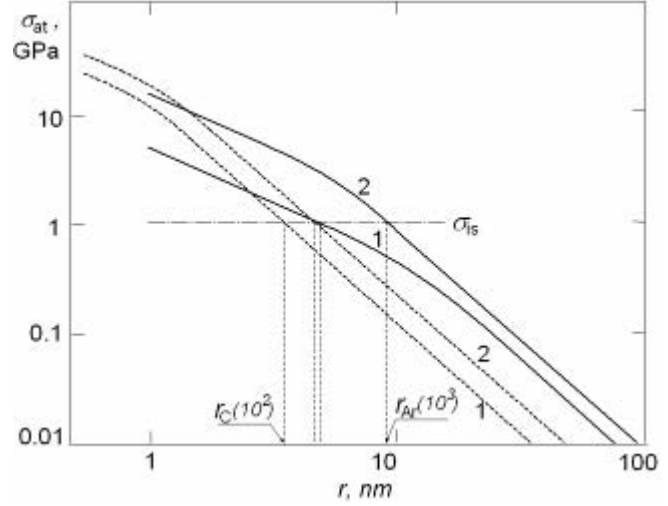


Figure 2. Spatial dependence of total acoustic stress, generated by C^+ (curves 1) and Ar^+ (curves 2) with energies 100 eV (dashed) and 1 KeV (solid) in carbon

The equations (1), (2) are correct only for distances $r_0 \ll r_{at} = (R/s)^2/\beta$ when one can neglect the sound absorption on the boundary frequency s/R . So, taking for the index of absorption $\beta = 2 \text{ m}^{-1} \cdot \Gamma \Gamma_{\text{H}}^{-2}$ (the typical value for hard dielectric materials like sapphire) we get $r_{at} = 3 \text{ nm}$ ($r_{at} = 20 \text{ nm}$) in case of C^+ ion with energy 100 eV (1000 eV). For maximum of total acoustic stress the following estimate is correct:

$$\sigma_{at}(\vec{r}_0) \approx \begin{cases} \frac{R}{2r_0} \frac{\Gamma E \eta + KV_1 + 2s\sqrt{2ME} \cos \theta}{V}, & r_0 \ll r_{at}, \\ \frac{\Gamma E \eta + KV_1 + 2s\sqrt{2ME} \cos \theta}{\sqrt{2\pi e} \beta s^2 r_0^2}, & r_0 \gg r_{at}. \end{cases} \quad (3)$$

The spatial dependence of total acoustic stresses from C^+ and Ar^+ TEPs (curves 1 and 2, respectively) with energies 1 KeV (solid lines) and 100eV (dashed lines) is shown in Figure 2. The point of observation lies in axis $\theta = 0$. When the stress exceeds a threshold of activation then corresponding kinetic process is stimulated in the irradiated matter. So, the displacement of interstitials from stoppers goes everywhere in the neighborhood of TEP where the acoustic pulse amplitude $\sigma_{at}(\vec{r})$ exceeds the value of the activation energy $\sigma_{is} = U_{is}/\Omega_{is} \sim 1 \text{ GPa}$ of the displacement (see Figure 2). Here $U_{is} \sim 0.1 \text{ eV}$ is the energy of migration of the interstitial, $\Omega_{is} \sim 2 \cdot 10^{-23} \text{ cm}^3$ is the interstitial volume in carbon. As one can see from Figure 2, the radiuses $r_C(E)$ and $r_{Ar}(E)$ of the activation zones around TEPs of C^+ and Ar^+ where the over-barrier movement of diffusants occurs depends considerably on sort and energy of the ion.

REFERENCES

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